3.3 Explaining and Predicting Climate Change

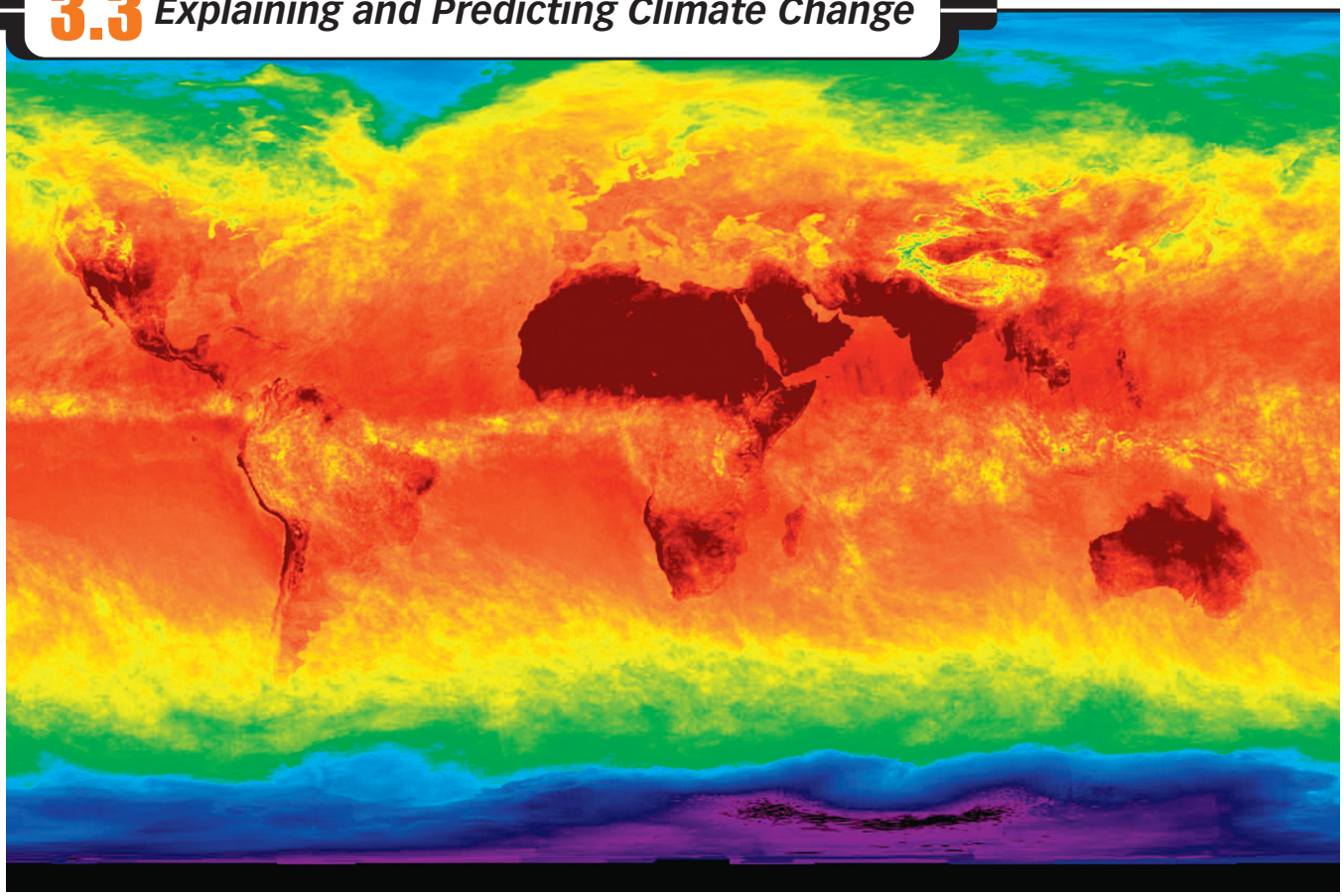


Figure C3.29: A detector mounted on a satellite orbiting Earth measures surface temperatures across the entire globe. This image is an average for the month of April 2003.

For many people, part of their morning routine involves checking the radio, newspaper, TV, or Internet to find out what the **weather** will be like that day.

The predictions made by meteorologists are not always perfect, especially if they are long-term forecasts. Earth's **climate** system is complex—this makes it difficult for atmospheric scientists to make reliable weather forecasts for a vicinity, even with the most powerful weather-simulating computers at their disposal. Predicting changes in Earth's climate is even more challenging.

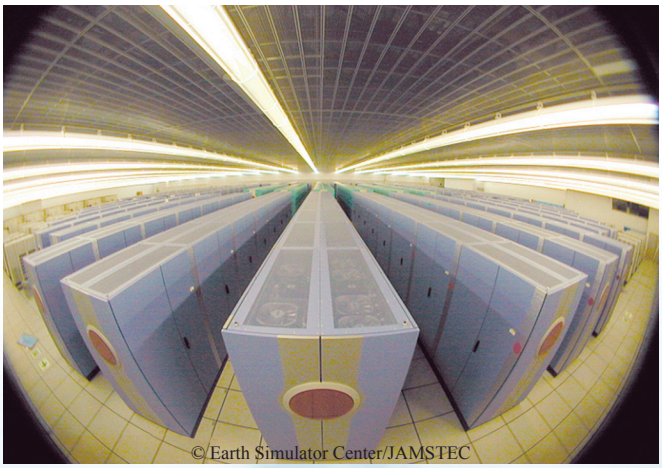


Figure C3.30: The world's most powerful supercomputer, the Earth Simulator, is used to model processes such as plate tectonics and deep ocean currents to help scientists predict future changes to Earth's climate.

- weather: the state of the atmosphere in terms of variables such as temperature, cloud cover, precipitation, and humidity for a particular place at a particular time
- climate: the average of daily and seasonal weather events that occur in a region over a long time period

A Story of Change

So far in Unit C you have witnessed an amazing story of changing landscapes and climates. This remarkable environmental diversity is matched only by the variety of organisms that have lived on Earth. These include stromatolites soaking up the sun in shallow beach-front pools, bizarre creatures inhabiting a tropical coral reef, dinosaurs roaming rain forests and deep seas, and herds of large grazers and woolly giants surviving repeatedly advancing ice sheets. And, finally, after all of this change, after four tumultuous eras filled with survival and extinction, you have come to the recent part of the story—the Holocene Epoch.

The Epoch of Recent Time

The Holocene Epoch began approximately 10 000 years ago at the time of the great melt that followed the last glaciation. By that time, people were inhabiting North America. The oldest signs of the existence of people on this continent are stone tools found in the Bluefish Caves in the Yukon—these are determined to be approximately 16 000 years old. Scientists may indeed find older evidence of humans in North America. The rapid melting of the Laurentide Ice Sheet opened up an ice-free corridor extending south through Alberta, providing North America's early northern residents with a passage south.

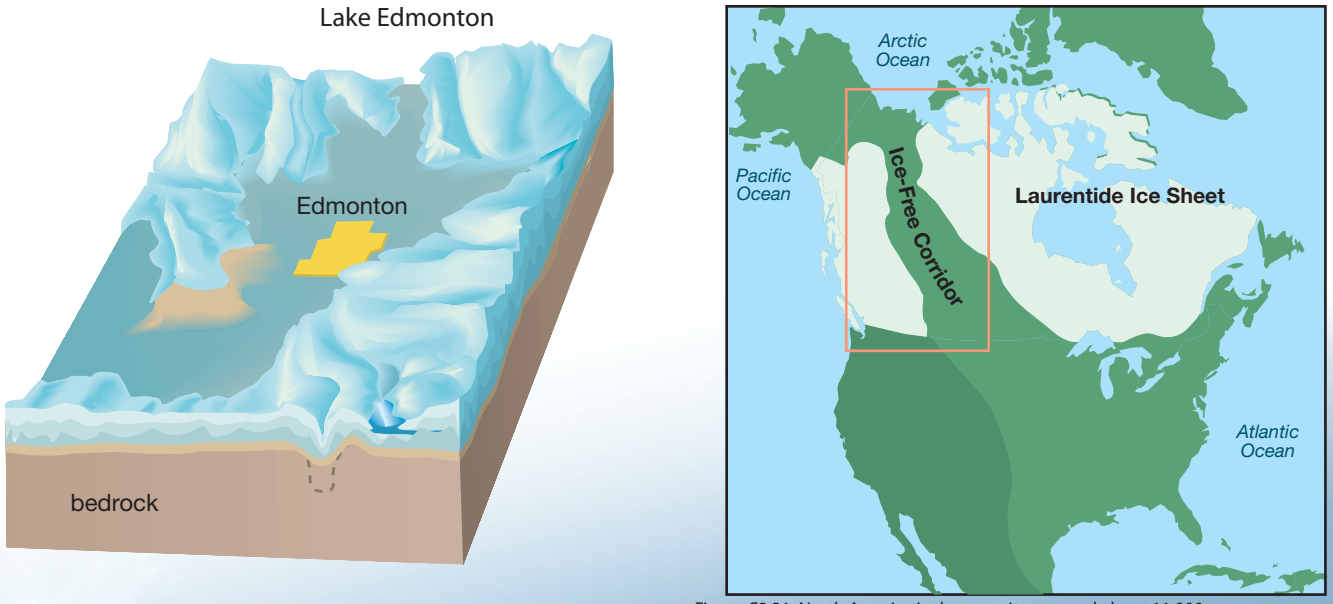


Figure C3.31: North America is shown as it appeared about 11 000 years ago.

Traditional stories of First Peoples speak of a world of water out of which the Great Spirit created the land. Indeed, as the Laurentide Ice Sheet completely disintegrated, it did release a great deal of water. This filled enormous glacial lakes, such as the 150-km-long glacial Lake Edmonton, which submerged the Edmonton area 12 000 years ago.

16 000 years ago: oldest archaeological evidence of humans living in North America

Weather Events: Cause, Correlation, and Probability

Before continuing with your work on climate change, it is important to understand the relationship between cause, correlation, and probability. These terms are important when evaluating the validity of theories concerning Earth's climate. In Practice questions 7 to 11, you will apply these ideas to the study of a small-scale weather event before applying them to a long-term global climate trend.

Practice

It doesn't matter whether you are going to a soccer practice, having a family picnic, or just mowing the lawn. Thunderstorms are a natural event that must be respected when it comes to summertime activities in Alberta. Many signs indicate a thunderstorm is coming, including a darkening sky and a noticeable drop in temperature. A sign that rain is just moments away is the sudden appearance of strong wind gusts.

Figure C3.32: A thunderstorm is approaching.

To sort these things out, it is important to keep these words in mind: cause, correlation, and probability.

- cause: a phenomenon that brings about an effect or a result
- correlation: one phenomenon that accompanies another
- probability: a measure of how likely it is that an event will occur

7. Explain the difference between cause and correlation.
8. Attempt to prove or disprove the statement, "In the summer it always seems to get cooler just before it rains. Therefore, a decrease in temperature must cause rain."
9. Does the occurrence of rain and a drop in temperature have a causal relationship or a correlational relationship?
10. Explain how you could use your answers to questions 8 and 9 to make predictions about the likelihood of rain. What level of certainty would you have in your prediction?
11. Based on this exercise, infer two elements that determine the level of certainty you can have in a prediction.

Fluctuating Climate

The current epoch—the Holocene—is just one time period of warming following one of several glaciations that occurred in the Quaternary Period. If this pattern of repeated glaciation continues, Alberta will experience its next glaciation within the next 100 000 years. Looking back over Earth's history before the Quaternary Period, there were several blocks of time containing repeated glaciations that date all the way back to Snowball Earth in the Precambrian Era. In this lesson you will learn about some theories concerning the causes of these cold periods and the repeated glaciations they contained. Before learning about these theories, you need to review the global climate record during Earth's history. Some changes in climate seem to be chaotic in nature, while others seem to follow a pattern.

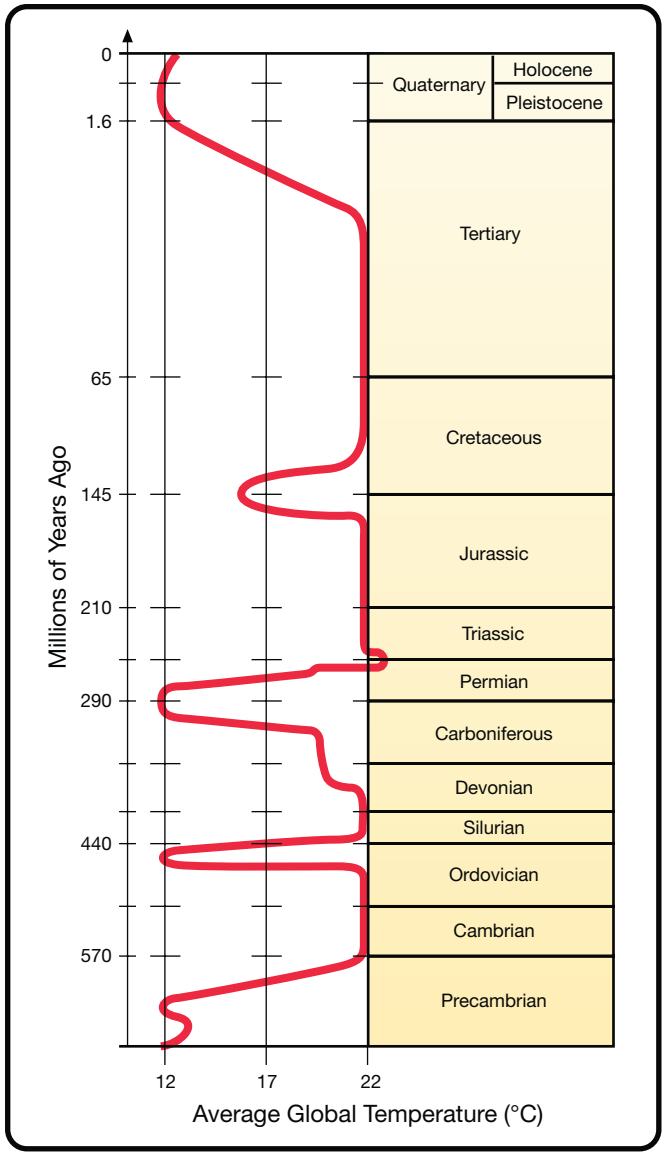


Figure C3.33: Evidence contained in rock strata around the world indicates that during most of its history, Earth was warmer than it is today. During these warmer times, it is unlikely that continental ice sheets like those in Antarctica and Greenland could stay frozen. However, this hot climate was punctuated by several long cold periods, each lasting millions of years. Today, Earth is experiencing one of these major cold periods. Remember that this is a very simplified graph. Much evidence is still being gathered.

Possible Causes of Glaciation Periods

It was mentioned earlier in this lesson that the most powerful supercomputers are used to create mathematical models that attempt to describe Earth's climate. These models involve studying links between the amount of solar radiation reaching the planet and each layer of Earth itself: the atmosphere, the lithosphere, and the **hydrosphere**.

hydrosphere: all the water at or near Earth's surface

Because these links are so numerous, and because the interactions are so intricate, the most powerful computer hardware and software available struggle to generate reasonably accurate models. As you read through the following possible causes of glaciation, you must keep this complexity in mind. Rather than wondering which of these theories is the correct explanation, it would be more helpful to think about which combination of these effects is most likely to play a significant role.

Continents Heading North

The timing of long periods of repeated glaciations, such as those that happened in the Precambrian Era, Jurassic Period, and Pleistocene Epoch, appears to be random. This may be due to the random nature of plate tectonics, which is their most probable cause. One theory concerning the cause of these cold snaps is that they occur when Earth's tectonic plates are in certain positions. It seems now that large land masses must be near the poles, such as Antarctica and Greenland, for a period of repeated glaciations to occur. This is because continental ice sheets must form on land to cause glaciations. As snow and ice begin to accumulate, the forming ice sheet takes on a climate of its own. Because an ice sheet is white, it reflects most of the solar energy that hits it back into space. This has an overall cooling effect on the planet.

The Ocean Is a Heat Pump

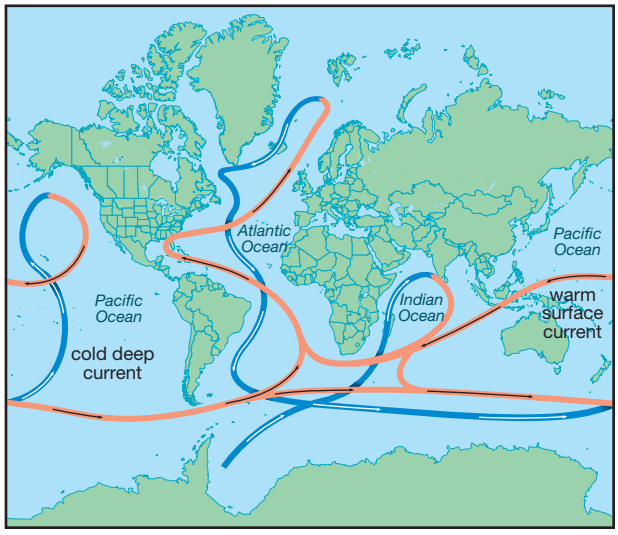
Do you know how your refrigerator works? A refrigerant fluid circulates through tubes. The fluid circulates, picking up heat from the inside of your fridge and dumping it into your kitchen. The oceans have giant convection currents that transport heat in a similar way. Collectively, they are called the **global conveyor**. The global conveyor currently has a warming effect on some parts of the world and a cooling effect on others. For example, in the North Atlantic Ocean, the conveyor transfers heat from the warm tropics and moves it between Iceland and Scotland. Much of the released heat is carried to Europe by prevailing winds. This explains why most European countries are warmer than Canada even though they are just as far north as Canada.

There is the opposite effect in Antarctica. An ocean current encircles Antarctica, which reduces the amount of heat the continent can receive from the southern tropics. This explains why Antarctica is the coldest place on Earth. Changes in the flow of ocean currents may explain the Pleistocene Epoch cold snap. Forty million years ago, Australia separated from Antarctica—this created the Indian Ocean and allowed the ocean current to circulate around Antarctica. The cooling effect encouraged the formation of the Antarctic Ice Sheet that led to the Pleistocene Glaciations.

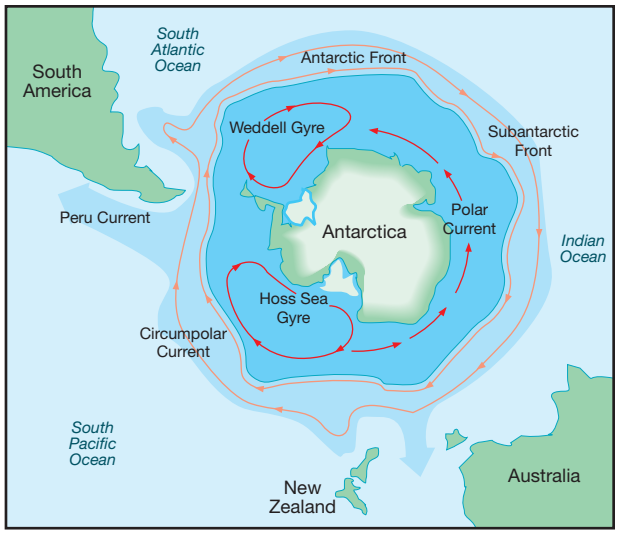
global conveyor: the system of ocean currents that circulates warm water away from the tropics near the ocean's surface

The system also recirculates the cold water of the polar regions using currents that flow in the opposite direction in the deep ocean.

The Global Conveyer



Antarctica's Ocean Current



The Long and Short of Volcanoes

Old volcanic activity may have contributed to long-term climate change. As discussed in Chapter 2, volcanoes are believed to have been a major contributor to the extinction of many species in the Permian Period. Volcanoes can also contribute to short-term fluctuations in climate, as demonstrated by the temporary cooling effect caused by the 1991 eruption of Mount Pinatubo in the Philippines.

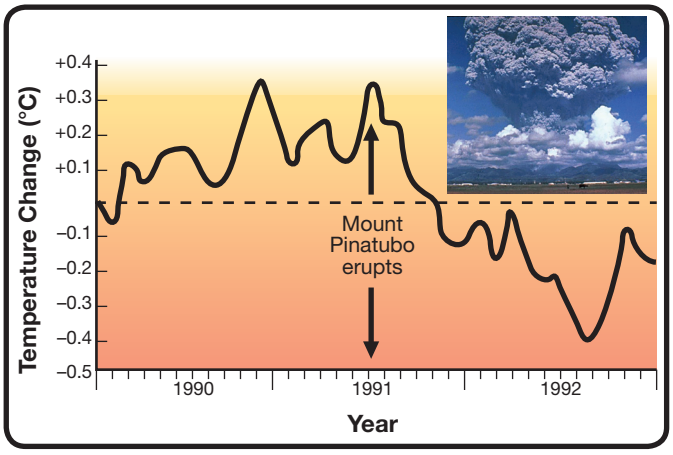


Figure C3.34: The eruption of Mount Pinatubo in 1991 had an effect on the world's climate.

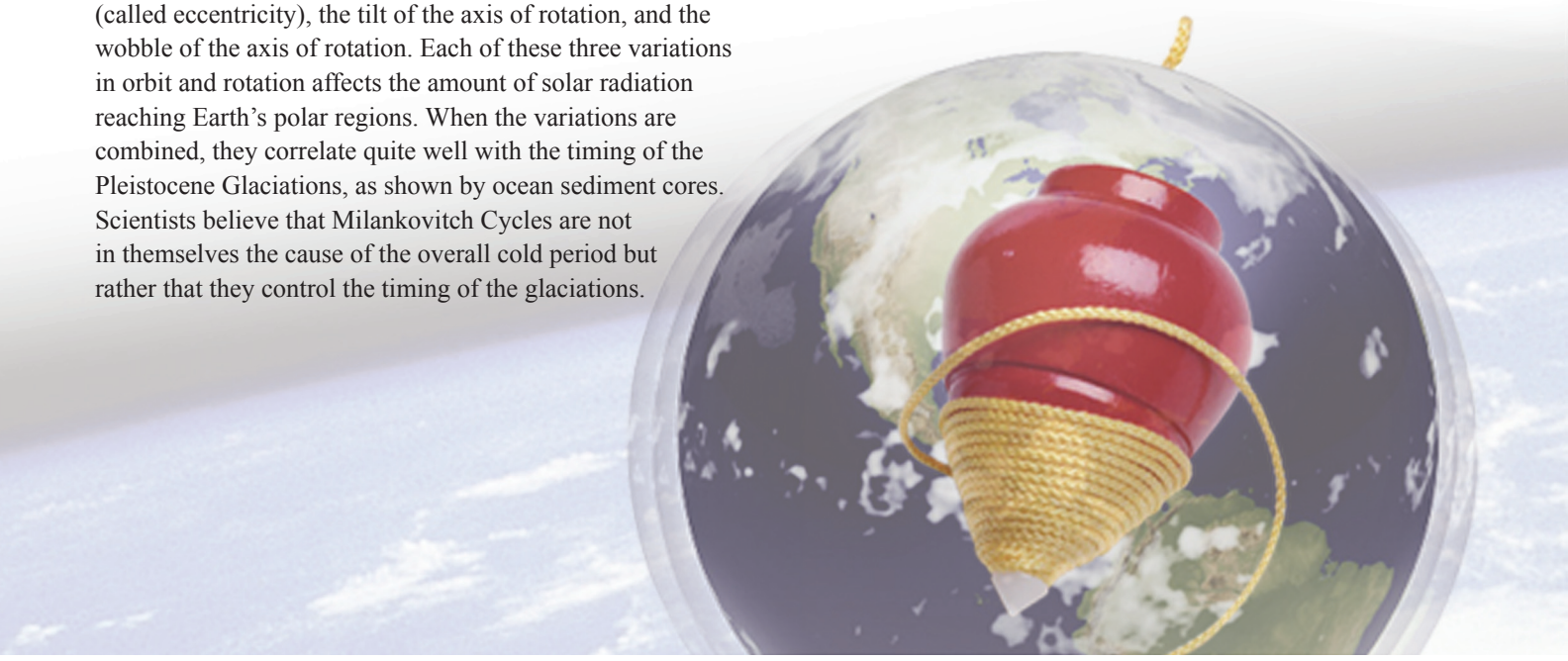
Wobbly Earth

During each of the major cold periods in Earth's history, ice sheets have advanced and retreated several times. The repeated glaciations that have occurred during major cold periods seem to match changes in Earth's orbit around the Sun and Earth's rotation on its axis. This is called the Milankovitch Theory, after the scientist who first suggested this correlation between changes in Earth's orbit and the occurrence of glaciations. Milutin Milankovitch found that Earth's orbit varies in three ways: the shape of the orbit (called eccentricity), the tilt of the axis of rotation, and the wobble of the axis of rotation. Each of these three variations in orbit and rotation affects the amount of solar radiation reaching Earth's polar regions. When the variations are combined, they correlate quite well with the timing of the Pleistocene Glaciations, as shown by ocean sediment cores. Scientists believe that Milankovitch Cycles are not in themselves the cause of the overall cold period but rather that they control the timing of the glaciations.

Our Moody Sun

Scientists have discovered that the Sun doesn't always shine with the same intensity. These changes in the intensity of solar radiation seem to follow a regular pattern determined by the frequency of sunspots. During times when there are more sunspots, additional energy is released by the Sun. Most climatologists consider variations in the sunspots to have only a minor impact on climate change because the differences in energy output are small (0.1% to 0.2%). However, there appears to be a correlation between the Maunder Minimum from 1645 to 1715—a time of very low sunspot occurrence—with an unusually cold period that occurred during the Little Ice Age in Europe. However, more recent theories about the causes of the Little Ice Age tend to be based more on changes in the North Atlantic Ocean's circulation current than on sunspots. One theory suggests a release of fresh water into the North Atlantic Ocean slowed down the circulation current that normally warms Europe.

Figure C3.35: Europe has been subjected to periods of cold temperatures at several times in its history.



Practice

12. The table in this question summarizes possible causes of glaciation. The causes are listed in the left column. The possible effects of each cause on Earth's layers, as well as the amount of solar radiation received on Earth's surface, are the headings across the top of the table. No answers are required for boxes with Xs.

POSSIBLE CAUSES OF GLACIATION AND THEIR EFFECTS

Possible Causes of Glaciation	Effects on Earth's Atmosphere	Effects on Earth's Lithosphere	Effects on Earth's Hydrosphere	Effects on Solar Radiation Received on Earth's Surface
Plate Tectonics	X			
Global Conveyor				X
Volcanic Activity		X	X	
Milankovitch Cycles	X	X	X	
Variations in the Sun's Energy Output	X	X	X	

Complete this table by adding a description of how each cause of glaciation affects both Earth's layers and the amount of solar radiation received on Earth's surface.

13. Consider the table you completed in question 12. Which causes of glaciation show the greatest degree of interconnectedness by the effects they have upon Earth?

Investigation

Return to Vostok

Science Skills

✓ Analyzing and Interpreting

Problem

Is there a correlation between the average temperature and atmospheric carbon dioxide concentrations over the last 160 000 years?

Background

In Lesson 3.2 you analyzed ice-core data from Lake Vostok, Antarctica. You constructed a graph showing average temperature fluctuations over 160 000 years. Refer to "Vostok Spreadsheet and Data" from the Science 20 Textbook CD, and obtain the "Temperature and Carbon Dioxide over 160 000 Years" handout.

Analyzing Data

Analyze the graph showing average temperature and carbon-dioxide concentrations over the past 160 000 years.

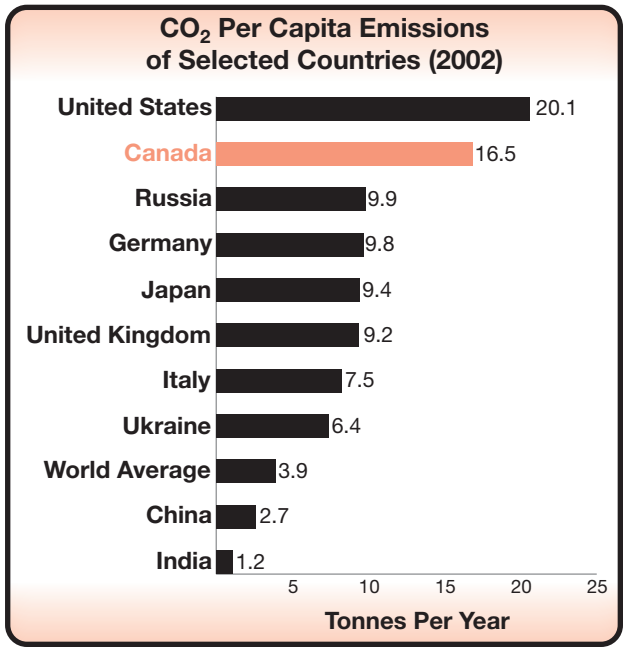
1. Using the data, identify whether there is a correlation between the two variables of average temperature and carbon dioxide concentration. Provide evidence.

Conclusion

2. Does this mean that changes in the concentration of atmospheric carbon dioxide actually cause the changes in average global temperature?
3. Determine if changes in the amount of atmospheric carbon dioxide correlated with the last two glaciations are caused by human activities.

The Enhanced Greenhouse Effect

Earth's atmosphere contains gases, such as carbon dioxide and methane, that trap heat near Earth's surface. Without this natural insulating effect, Earth would be much colder than even the coldest ice age. As you saw when you analyzed the Vostok ice-core data, carbon dioxide in the atmosphere can change drastically. This can occur due to natural events, including volcanic activity and the weathering of carbonate rocks. These variations appear to correlate with changes in the average global temperature over the past 160 000 years. Changes in carbon dioxide, in combination with other factors such as the Milankovitch Cycles and global ocean circulation, may have amplified the effect on the atmosphere's temperature.



In more recent times, there has been a sharp increase in the concentration of carbon dioxide in the atmosphere. This increase coincides with an exponential increase in the emissions of carbon dioxide since the Industrial Revolution. The largest human-caused source of atmospheric carbon dioxide is the burning of fossil fuels. Many scientists believe this increase is enhancing Earth's natural greenhouse effect, shown by a significant increase in the average global temperature during the last century (see Figure C3.36). Computer models predict that as carbon dioxide emissions continue to rise, the effect will be further increases in the average global temperature. Canada and Alberta are contributing more than the global per person average share of these emissions due to the use of energy sources that produce carbon dioxide emissions as well as poor energy efficiency. Because many of the activities that lead to carbon dioxide emissions are under the control of people, there is a possibility that global climate change can be reversed.

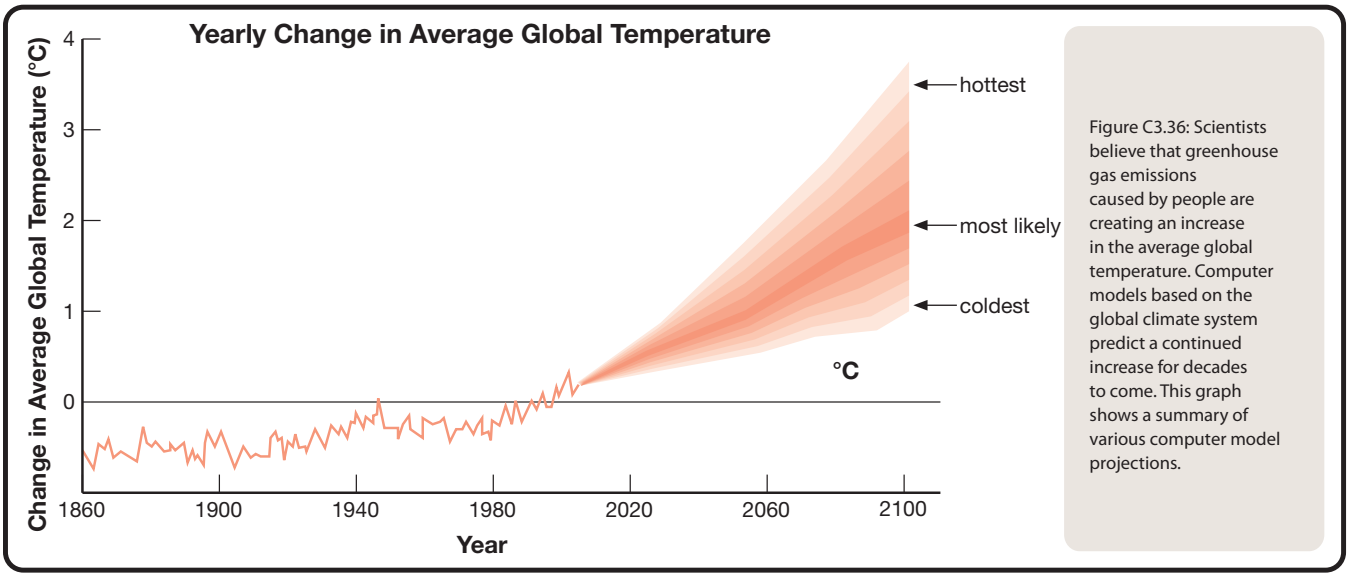


Figure C3.36: Scientists believe that greenhouse gas emissions caused by people are creating an increase in the average global temperature. Computer models based on the global climate system predict a continued increase for decades to come. This graph shows a summary of various computer model projections.

Could Global Warming Cause Global Cooling?

This question may seem strange, but some current models of climate change actually predict this. The prediction that global warming could end up causing a drastic cooling demonstrates the complex nature of Earth's climate system. As Earth warms due to the enhanced greenhouse effect, mountain glaciers and continental ice sheets are melting. Over the past several decades, the Greenland Ice Sheet has been shrinking in size and releasing fresh water into the North Atlantic Ocean. If the atmospheric temperature were to get hot enough, the rate of melting of the Greenland Ice Sheet would increase. If enough fresh water is added to the North Atlantic, it could slow down warming tropical currents. The result could be similar to what may have occurred to cause the most recent ice age: less heat being pumped toward the poles from the tropics. This could have a rapid cooling effect, which could result in advancing ice sheets in the north. Changing one variable in the complex system of Earth's climate, for example the amount of carbon dioxide, can have an unexpected effect on the whole system.

Utilizing Technology

The North Atlantic Conveyor

An applet titled "North Atlantic Conveyor" is available on the Science 20 Textbook CD. This animation shows the North Atlantic Conveyor in action, pumping heat up from the tropics to Canada and northern Europe.

Science Skills
✓ Analyzing and Interpreting

Analysis

1. Describe the effect of adding large volumes of cool fresh water from Greenland to the North Atlantic Conveyor.
2. Explain why the outcome is somewhat paradoxical.

3.3 Summary

The Holocene Epoch is the final page in this story of Alberta. It began approximately 10 000 years ago and is still in progress. The foundations established by scientists, like James Hutton and Charles Lyell, have revealed that to understand the past, people must rely on processes observable in the present—theories must carry the burden of evidence. This same line of thought applies to projecting future changes. Scientists strive to understand the processes that have caused climate changes in the past and hope to apply this knowledge to predict future climate change. You have seen that this can be a difficult and complex task, as many theories and processes combine in complicated ways. When predicting outcomes in a complex system like Earth, total certainty can never be reached. A lack of certainty should not prevent people from acting.

3.3 Questions

Knowledge

1. Copy and complete the table, and fill it in using brief descriptions. Make sure to give yourself enough room.

Time Frame	Description of Average Temperature Fluctuations	Theory of Cause	Description of Theory
Earth's Entire History		Plate Tectonics	
		Volcanic Activity	
Pleistocene and Holocene		Milankovitch Cycles	
		Natural Carbon Dioxide Fluctuations	
Little Ice Age		Variations in Solar Intensity	
Last 100 Years		Enhanced Greenhouse Effect	

2. Define the term *Holocene Epoch*.

3. Explain why 100% certainty cannot be achieved when making climate predictions.

4. What major theme dominates the story of Alberta?

Applying Concepts

5. The issue of climate change involves the intersection of science with technology and society. Create a table that starts with these categories by listing the aspects of this issue that fall into each category. Show connections by using circles and arrows.

Science	Technology	Society

Chapter 3 Summary

In Chapter 3 you have learned how Alberta has changed during the Cenozoic Era. You discovered that mountains were built and mammals flourished in a cooling climate. You found out that ocean-sediment cores and continental ice-sheet cores can be used as records of climate during the past 65 million years. You studied several possible causes of climate change, and you discovered that human activity—including the burning of fossil fuels—is on that list.

In Unit D you will examine how change, often at the hands of humans, affects living organisms. You will see how ecosystems and organism populations interact in the present and change over time.

Summarize Your Learning

In Chapter 3 you learned a number of new terms, concepts, and techniques for problem solving. It will be much easier for you to recall and apply the information you have learned if you organize it into patterns.

Since the patterns have to be meaningful to you, there are some options about how you can create this summary. Each of the following options is described in "Summarize Your Learning Activities" on pages 552 and 553. Choose one of these options to create a summary of the key concepts and important terms in Chapter 3.

Option 1: Draw a concept map or a web diagram.	Option 2: Create a point-form summary.	Option 3: Write a story using key terms and concepts.	Option 4: Create a colourful poster.	Option 5: Build a model.	Option 6: Write a script for a skit (a mock news report).

Chapter 3 Review Questions

Knowledge

1. Explain the origin of the Big Rock at Okotoks, Alberta.
2. Use the "Geological Time Scale" on page 312 to sketch a diagram showing how the Cenozoic Era is broken down into periods and epochs. Include the start and end time of each time period.
3. Describe how glaciers move.
4. Explain why the Cenozoic rock formations at Cypress Hills are still intact, whereas Cenozoic rock formations in other parts of Alberta and Saskatchewan have been disturbed.
5. Explain what caused the draining of the Bearspaw Sea near the beginning of the Cenozoic Era.
6. Define the term *glaciation*.
7. Describe how the Rocky Mountains appeared before they experienced the glaciations of the Pleistocene Period.
8. Describe the climate change during the Tertiary Period. Infer a possible reason for this change.

9. Identify what two groups of animals took the place of large dinosaurs as the dominant life forms of Alberta in the early Tertiary Period.
10. Describe Alberta in the late Tertiary Period.
11. Explain how scientists have been able to measure the average global temperature change during the last 65 million years.
12. Describe how the climate during the Quaternary Period was different than the climate during the Tertiary Period.
13. Describe how each of the following features form. Give an example of each.
    - **a.** continental ice sheet
    - **b.** mountain glacier
14. Describe how glaciers have shaped the land as shown in Figure C3.37 and Figure C3.38.

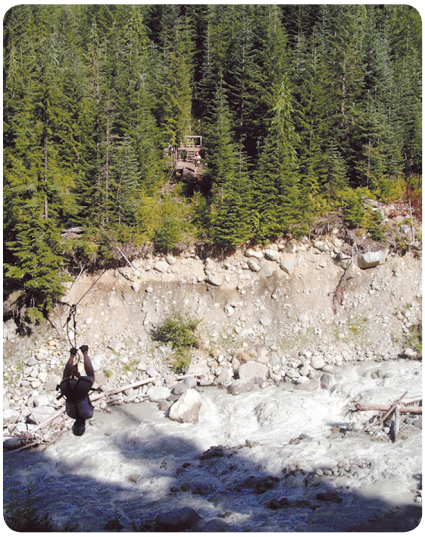


Figure C3.37: An ecotourist uses a zip line to cross a glacier-fed creek near Whistler, B.C.

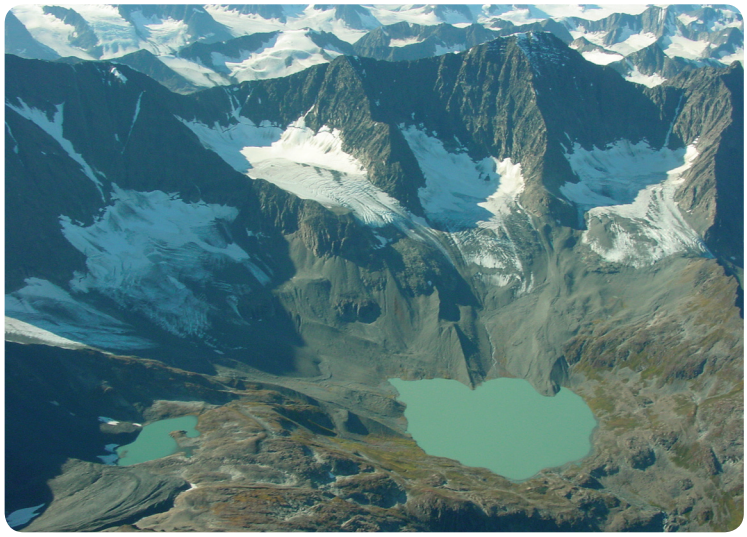


Figure C3.38: Glaciers have shaped the Chugach Mountains area of Alaska.

15. Describe how the most detailed information concerning average global temperature was collected and analyzed to determine Earth's climate over the past 420 000 years.
16. Describe the Wisconsin Glaciation.
17. Explain how scientists can determine in what direction the Laurentide Ice Sheet flowed during the Wisconsin Glaciation.
18. Explain how scientists can determine how far south the Laurentide Ice Sheet advanced.
19. Describe how mountain glaciers have changed the appearance of the Rocky Mountains.
20. Explain how glaciers help provide a basic need for many communities.
21. How is the trend in increasing average temperatures around the world affecting mountain glaciers and ice sheets?
22. Explain the difference between weather and climate.
23. Explain how scientists are working to reduce uncertainty about their predictions concerning global climate change.
24. Briefly summarize the changes in Earth's average global temperature over the course of its 4.5-billion-year history.

25. Explain how continental drift caused by plate tectonics can lead to climate changes.
26. Once an ice sheet forms, explain how it reduces the amount of solar radiation absorbed by Earth.
27. Explain how the Milankovitch Variations on Earth's orbit and rotation affect Earth's climate.
28. Explain what evidence shows a correlation between atmospheric carbon dioxide concentration and average temperature.
29. Describe the current impact of people on the global climate.
30. Explain how the enhanced greenhouse effect could actually lead to a cooling of Earth's northern regions.

Applying Concepts

Figure C3.39: Angiosperms (flowering plants) with pointed leaves are found in warmer climates, while angiosperms with rounded leaves are found in cooler climates.

31. Refer to Figure C3.39. What inference could you make concerning past climates if you found fossils of angiosperms with pointed leaves in Canada's Arctic?

Use the following information to answer questions 32 to 34.

Locate the video clip called "Career Profile: Columbia Icefield Tour Guide" on the Science 20 Textbook CD. Play the video. Use the information provided to answer questions 32 to 34.

32. Describe the process that produces glacial ice.
33. Explain why glacial ice is said to have the properties of a plastic.
34. Identify three uses for the fresh water that flows from glaciers.

Use this article to answer questions 35 to 41.

Researcher computes climate change

By Chris Smith

June 17, 2003 – A University of Alberta professor who studies computerized climate modelling has found that his field of research is in the middle of a brewing controversy. Dr. Andrew Bush specializes in paleoclimate modelling and supercomputing in the U of A Department of Earth and Atmospheric Sciences.

To help others understand his research, Bush begins by explaining the difference between climate and weather. "Climate includes all the processes that give us our weather," he said. "There is a fundamental difference between climate prediction and weather prediction."

Weather prediction occurs regionally and over the short term; climate is the average of all the weather events over a longer time period. For Bush's climate models, this goes back 21 000 years to the end of the last glacial advance.

Using such models, as well as arctic ice core samples and historical weather data, the United Nations Intergovernmental Panel on Climate Change (IPCC) concluded that although there are uncertainties in the ultimate cause of climate change, all indications point to human influence as a contributing factor.

Quickly following the release of the 2001 IPCC report, the results produced by computer modelling were devalued after they became the center of controversy and misunderstandings. "It's easy to be skeptical of something that can never be predicted with 100 percent accuracy. A lot of my work has been on simulating the climate and then comparing the model results to the data records," said Bush.

This kind of verification is essential because, Bush said, "the models are an approximation of reality; they are not reality itself . . . . The IPCC (report) is the best statement of our current knowledge, and that knowledge is certainly going to change in the future." Just how our knowledge will change will depend on more accurate data and better climate modelling on faster computers. This challenge has been wholly taken up by the Earth Science Center in Japan, which designed and built the Earth Simulator. The fastest computer ever built, the Earth Simulator operates at 40 Terra flops per second, or 40 trillion computations per second, which is five times faster than the previous best.

"Climate research is limited by the hardware," Bush said. "The number of computations involved in climate modelling necessitates the use of leading edge supercomputers."

Global climate change has presented supercomputing and climatologists, like Dr. Bush, with a great challenge. Armed with better computer hardware and climate modelling techniques, scientists' understanding of the climate system and identification of the human contribution to climate change may determine how we can avoid further environmental damage.

"Climate modelling is our best and only tool for predicting the future of our global environment, as well as the consequences of our actions as a species," Bush said. "Can climate modelling save the world? No—all it can do is tell us why the world is changing. Saving it is up to all of us."

35. What is the brewing controversy referred to in the article's first sentence?

36. Summarize the conclusion made by the United Nations Intergovernmental Panel on Climate Change (IPCC).

37. Explain the significance of the conclusion made by the IPCC.

38. What reason does Dr. Bush give for people being skeptical about computer modelling?

39. How do scientists verify computer models used to predict future climate changes?

40. Does Dr. Bush consider scientific knowledge to be static or changing? Justify your answer.

41. Describe the world's leading technology in the area of climate modelling.